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Review Article

Research Highlights on the Evolution of Precambrian Crust of Peninsular India: Constraints from Recent Zircon U-Pb Geochronological Results

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During the last quadrennial period, (2012-2016), many aspects of the Precambrian geology of the Indian peninsula were revisited by Indian geoscientists and their collaborators with the advantage of modern analytical techniques for geochronology as well as new perspectives on global geodynamics in space and time. Important contributions were made to the Archean and Proterozoic geological evolution of the Dharwar, Singhbhum, Bundelkhand and Bastar cratons, the granulite gneiss terrains, especially the Southern Granulite Terrain (SGT) and the Eastern Ghats Granulite Terrain (EGGT) and also the Proterozoic sedimentary Basins of peninsular India. Significantly, these studies have provided evidence for Paleo- to Eoarchean crustal remnants apart from placing precise age constraints on geological events. Most authors favoured the interpretation of Archean geodynamics in a plate tectonics conceptual framework for the assembly of Indian terranes in the supercontinent reconstructions, as reviewed on the basis of a short compilation of published research articles.

Keywords: Precambrian Crustal Evolution; Peninsular India; Geochronology; U-Pb Zircon Ages

Introduction

Unravelling the geodynamic processes that underpin the formation, destruction and stabilization of Earth's continental crust in deep-time is fundamental to geosciences. Precambrian (>0.5 Ga) geodynamics has gained immensely from advancements in analytical technology relevant to radiometric age determination, especially, the *in-situ* U-Th-Pb dating of accessory minerals like zircon ($ZrSiO_4$) at a high spatial resolution, typically <50 µm. The last quadrennial period witnessed a proliferation of precise age and isotopic data constraining the chronology of magmatism, metamorphism and deformation of many Precambrian rock units in peninsular India. New *in-situ* zircon U-Pb ages along with $^{177}Hf/^{176}Hf$ isotopic data and in many cases zircon trace element compositions have been obtained, using the Secondary Ionisation Mass Spectrometry (SIMS), the Laser Ablation-Multicollector Inductively Coupled Plasma Mass Spectrometry (LA-MC-ICPMS) and LA-Quadruple ICPMS (LA-QICPMS). Peninsular India (here excluding the Himalayan region described elsewhere in this volume) presents one of the largest exposures of Precambrian crust in the world. Salient geological features of the region are summarised in Fig. 1 and reviewed by, among others, Naqvi (2005), Ramakrishnan and Vaidyanadhan (2008), Sharma (2009), Valdiya (2010), Sarkar and Gupta (2012). The Indian shield is made up of 5 cratons, viz., Dharwar, Bastar, Singhbhum, Bundelkhand and Aravalli cratons. These cratons are Archean granite-greenstone terrains that consist predominantly of low- to medium-metamorphic grade rock associations including: 1) grey gneisses, mostly Tonalite-Trondhjemite-Granodiorite (TTG) gneisses, 2) variably migmatised belts and rafts of metavolcanic and metasedimentary rocks, the greenstone belts and 3) intrusives; granitoids ranging in age from Mesoarchean to Mesoproterozoic, mafic dyke swarms, and variety of ultramafic to mafic bodies including kimberlites and lamproites. The Indian cratons are bordered by Proterozoic fold belts or 'mobile belts' that occur singularly or in pairs between the cratons. Also, the Proterozoic sedimentary Basins preserve upto a few kilometres thick supracrustal rock successions

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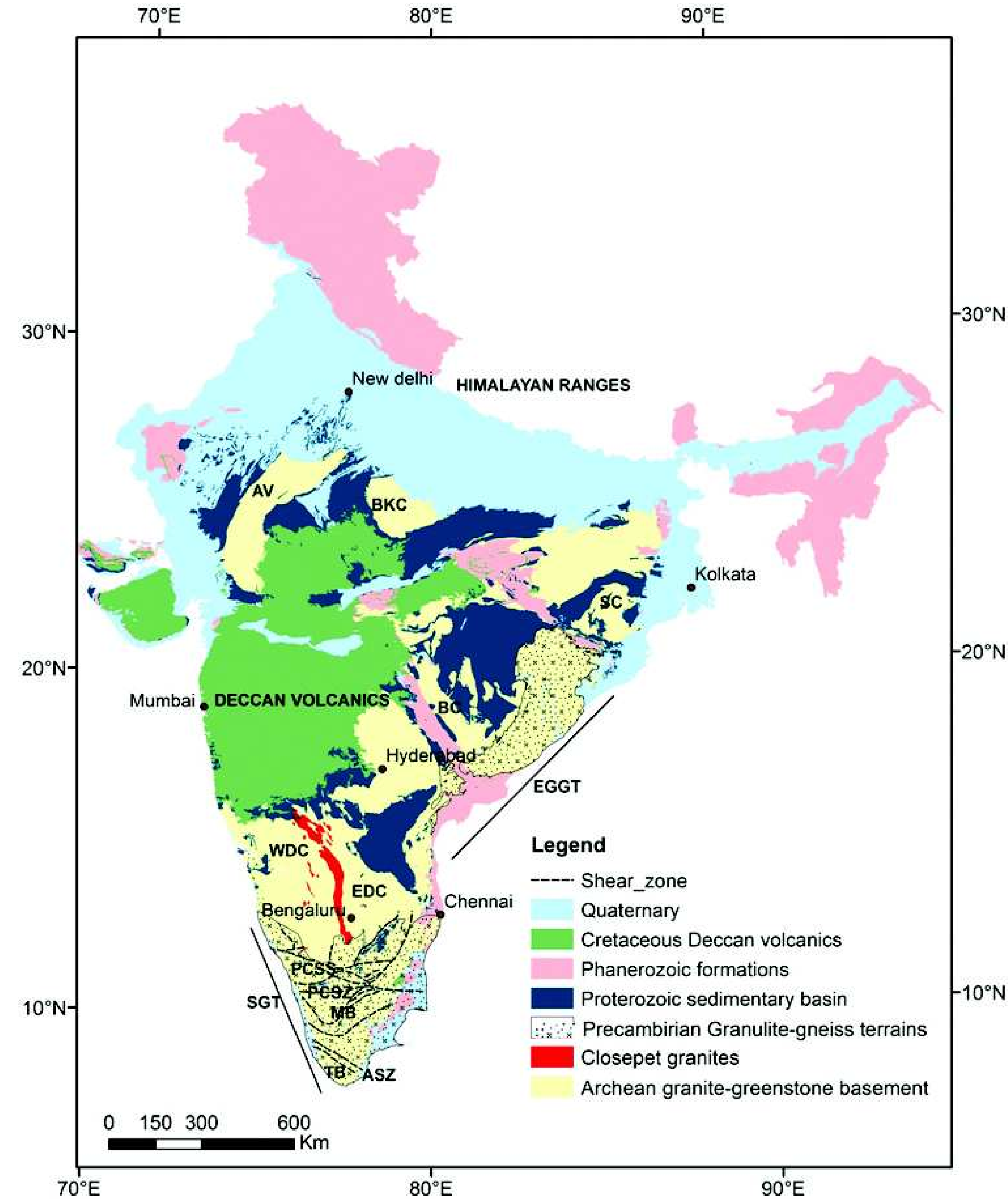

Fig. 1: Simplified geology of Peninsular India modified after Geological Survey of India (1996). Major Precambrian structural/ tectonic elements include Western Dharwar Craton-(WDC), Eastern Dharwar Craton-(EDC), Bastar Craton-(BC), Singhbhum Craton-(SC), Bundelkhand Craton-(BKC), Aravalli fold Belt-(AV), Southern Granulite Terrain-(SGT), Madurai Block-(MB), Trivandrum Block-(TB), Palghat Cauvery Shear System-(PCSS), Palghat Cauvery Shear Zone-(PCSZ), Achankovil Shear Zone-(ASZ), Eastern Ghat Granulite Belt-(EGGT). See text for more information

deposited in diverse facies and environments. Together, the rock units in these tectonic domains record a geologic history spanning ~3.0 billion years from ~3.5 to 0.5 Ga. Important contributions to the geochronology of these terranes are summarised and discussed briefly in the context of some current and emerging views on global geodynamics, outlined below.

It is well known that the Earth was formed around 4.567 Ga (Giga aeons) ago, and in its earliest stages witnessed dramatic events such as the giant impacts, magma ocean, core-formation and large-scale mantle differentiation and the formation of primordial crust (for a review see Harrison *et al*., 2009). A definite answer to the question; *when did the earliest terrestrial crust form*? remains elusive largely because of its poor preservation owing to factors such as rapid recycling because of the possible destruction of the early crust in asthenospheric convection and heavy bombardment' event during the late Hadean (>4.0 Ga). In this regard, the Indian peninsula has also been a target in the search for early continental crust *vis-a-vis* the oldest crustal components found in some parts of the world. The oldest dated rock on Earth is ~4.030 Ga old, from the Acasta gneiss complex, Slave craton, Canada (Mojzsis *et al.*, 2014 for a review). However, the most valuable source of information on the Hadean Eon comes from a few hundred detrital zircon grains that have been dated upto ~4.4 Ga by high resolution U-Pb dating methods, mainly using the Sensitive High Resolution Ion Microprobe-SHRIMP (e.g., Wilde *et al*., 2001). Most of these zircons are from a quartzite at Jack Hills, Mt. Narryer, Western Australia. A smaller population of Hadean zircons are sourced from Acasta gneiss and 4.08 Ga inherited zircon cores from an ~3.83 Ga granodiorite gneiss from Akilia Islands, west Greenland and a few Eoarchean TTG gneiss suites such as the Itsaq gneiss, west Greenland, the Saglek-Hebron gneiss complex, Labrador and the Anshan gneiss, North China craton and some supracrustal rocks that are tectonically interleaved in the Eoarchean gneisses, e.g., the Nuvvuagittuq belt, Quebec, Canada (Collerson *et al*., 1991; Nutman *et al*., 1996; Mojzsis and Harrison, 2002; O'Neil *et al*., 2007; Harrison, 2009). Although the origin of these Hadean zircons remains equivocal, many authors believe that they represent Hadean continental crust. Search for Paleo- and Eoarchean remnants in southern India have been partially successful as described below.

It is now widely appreciated that as much as 73% of the Earth's continental crust was extracted from the mantle by the end of the Archean (Belousova *et al*., 2010; Dhuime *et al*., 2012; Cawood *et al*., 2013) and major events in the accretion of Archean juvenile crust centred around 3.0 Ga and 2.7 Ga (Condie *et al*., 2000; Voice *et al*., 2011). However, the nature of the geodynamic process during the Archean remains controversial. The common question; *when did plate tectonics begin on Earth?* remains enigmatic. Many researchers favour a view that the late Paleoarchean/early Mesoarchean (*ca*. 3.3 to 3.0 Ga) marked a transition in the planet's geodynamic regime from a dominantly vertical (driven by mantle upwelling) towards dominantly horizontal (Phanerozoic-style plate tectonics) and that some form of plate tectonics operated since *at least ca*. 3.2 Ga (e.g., O'Neil *et al*., 2007; Condie and Kröner, 2008; Arndt, 2013). However, others have argued that modern style plate tectonics did not begin on Earth until the Neoproterozoic (Bedard *et al*., 2013 and references therein). It is also postulated that the Archean accretionary orogens comprise a special category of 'ultra hot' orogens (Chardon *et al*., 2011; Gerya, 2014 and references therein). Archean plate tectonic regimes may therefore be distinct compared to Phanerozoic plate tectonics on several counts, although many authors now believe that Archean plate tectonic regimes may not have been very different from the Phanerozoic plate tectonics. Such considerations provide a useful framework in which to interpret geological, geophysical and geochronological data on Archean cratons, research on the Indian cratons being no exception.

Growing evidence for Eoarchean (4.0-3.6 Ga) to Paleoarchean (3.6-3.2 Ga) Crust from Peninsular India

Many recent studies have documented new zircon U-Pb geochronological data mainly on the Dharwar and Singhbhum cratons together with new geological, petrological and geochemical information. These studies attest to the wide spread occurrence of Meso-Neoarchean gneiss and greenstone units in all the cratons of peninsular India, apart from localized evidence for Eo-Paleoarchean zircons. In the Western

Dharwar Craton (WDC), Jayananda *et al*. (2015) showed that much of the cratonic core in the southwestern part records two major periods of crust generation; ca. 3350-3280 Ma and 3230-3200 Ma. During these intervals, TTG accretion was pene-contemporaneous with greenstone volcanism and sedimentation. During the earlier phase, both high- and low-Al_2O_3 TTG magmas were emplaced. Their derivation involved melting of shallow and deep island arc-type crust that may have formed during the Eoarchean to Paleoarchean as indicated by their bulk geochemistry and Sm-Nd (T_{DM}) and zircon Lu-Hf model ages for the TTG suites. The Eoarchean-Paleoarchean context is also reflected by detrital (magmatic) zircons extracted from metasediments deposited between ~3.3 and 2.7 Ga as well as from modern stream sediments (Bhaskar Rao *et al*., 2008, Maibam *et al*., 2016; Lancaster *et al*., 2014; Santosh *et al*., 2014, 2015, 2016; Sarma *et al*., 2014; Hokada *et al*., 2013). The interpretations are also consistent with wholerock Sm-Nd isotopic systematics and model ages (Jayananda *et al*., 2015; De *et al*., 2015 for review). An interesting suggestion has been that the Coorg block, along the south-western margin of the WDC (Fig. 1) may comprise the oldest as well as an *exotic* terrane in southern India (Santosh *et al*., 2014, 2015, 2016). This is based on new age data on both meta-igneous rocks (granitoids, diorites, charnockites and volcanic flows) related to ancient arc magmatism and metasedimentary rocks (quartzite, ferruginous quartzite, banded iron formation-BIF, and calcareous/pellitic schists) considered as inter-arc shelf and pelagic accretionary packages. The igneous suites include multiple magmatic events around 3.5, 3.2, 2.7 and 2.5-2.4 Ga, while zircons from the metasediments include multiple discrete populations between 3.4 and 1.3 Ga. ε_{Hf} and T^{C}_{DM} model ages of the ~3.5 and 3.2 Ga magmatic zircons from the Coorg rocks indicate both juvenile and recycled crustal precursors of Eo-Mesoarchean ancestry, upto ~3.7 Ga. A detrital zircon grain from a ferruginous quartzite sample yielded Hf T^{C}_{DM} age of 4031 Ma, an indication of a Neohadean protolith in the provenance of the Eoarchean-Mesoarchean metasediments (Santosh *et al*., 2014). This result and the view that the Coorg may be an *exotic* block in southern India warrant further study with more data.

The geochronology of the Singhbhum craton also received considerable attention in terms of the antiquity of the Archean crustal components. The major crustal units of the craton include greenschist- to amphibolite-facies supracrustals of the Older Metamorphic Group (OMG), tonalite of the Older Metamorphic Tonalite Gneisses (OMTG), Tonalitie-Granite suites of the Singhbhum Granite (SG) batholith and the greenschist facies platformal sediments, mainly Banded Iron Formations interlayered with mafic and felsic volcanic rocks of the Iron Ore Group (IOG) (Mukhopadhyay *et al*., 2008). Zircons from TTGs of the OMTG and SG (Phases I, II, and III) reveal a polycyclic evolution of the Archean crust (Upadhyay *et al*., 2014). These authors showed that the tonalite and trondhjemite of the OMTG were emplaced at *ca*. 3.45-3.44 Ga together with Phase III of the Singhbhum Granite pluton, while granite of the OMTG were emplaced at *ca*. 3.35-3.32 together with Phase I and Phase II of the Singhbhum Granite pluton. These record an early phase of relatively high-grade metamorphism at 3.30-3.28 Ga followed by fluid-induced alteration during low-grade metamorphism at 3.19-3.12 Ga, and 3.02-2.96 Ga, apart from the *ca*. 2.52 Ga and 1.06 Ga metamorphic events recorded along the North Singhbhum Mobile Belt and the Singhbhum shear zone at the northern margin of the craton. The zircon grains in granites have inherited cores with ages of *ca*. 3.61 Ga and 3.46-3.41 Ga related to Eoarchean crust forming events. Nelson *et al.* (2014) reported new age data for detrital (igneous) zircons from metasedimentary enclaves, which constrain the regional deformation and amphibolite-facies metamorphism to the interval between 3325 and 3000 Ma. They summarised that (1) between 3530 and 3300 Ma, tonalite were emplaced, with volcanic, clastic and carbonate rocks and banded iron-formation (cycle 1) deposited onto tonalitic basement until 3375 Ma; (2) between 3325 and 3300 Ma, burial, deformation and uplift transformed the central part of the Singhbhum basement to tonalite gneisses, with cycle 1 sedimentary rocks incorporated into the gneisses as enclaves but preserved within synforms around the basement margins; post-3.3 Ga regional metamorphism, granodiorite intrusives were emplaced until *ca*. 3285 Ma; (3) BIF and clastic sedimentary rocks (cycle 2) were deposited around the margins of the craton onto the older (cycle 1) sedimentary rocks and adjacent gneissic basement until *ca*. 3.1 Ga; (4) a further episode of granite intrusion at 3090 Ma was followed by uplift and erosion of the central part of the craton prior to 2806 Ma; (5) volcano-sedimentary and banded iron-formation rocks were deposited during a third sedimentary cycle at *ca.* 2.8 Ga.

Several studies focused on the Eastern Dharwar Craton (EDC) with the objective of deciphering the chronostratigraphy of the greenstone belts and establishing the chronology of granite gneiss and granitoid components (Anand *et al*., 2014; Jayananda *et al*., 2015; Maibam *et al*., 2015, 2016; Tushipokla and Jayananda, 2013; Ram Mohan *et al*., 2014; Yang and Santosh, 2015; Hokada *et al*., 2013). Newer geochronology data are likely to appear in near future to throw further light on the pertinent petrogenetic problems.

Paleoproterozoic and Neoproterozoic cryptic sutures and ophiolites from the Southern Granulite Terrain (SGT), with its different crustal blocks characterised by distinct structural and age specrtra attracted considerable international attention, where, in many cases, existing geological models were revised in the light of new geochronological data. U-Pb zircon ages and Sm-Nd depleted mantle model ages (T_{DM}) of charnockites, associated migmatites and metasedimentary rocks and a limited dataset of zircon Lu -Hf isotopic data point to a complex genetic history for the charnockites in the SGT (e.g., Tomson *et al*., 2013; Brandt *et al*., 2014; Kröner *et al*., 2012; Plavsa *et al*., 2012, 2014; Peucat *et al*., 2013; Glorie *et al*., 2014; Bhattacharya *et al*., 2014; Taylor *et al*., 2015., Vijaya Kumar *et al*., 2016). For instance, the Sm -Nd T_{DM} age data suggest involvement of ancient crustal components (up to ~3.2 Ga) in the genesis of the Proterozoic charnockites from the Madurai and Trivandrum Blocks (Plavsa *et al*., 2012; Tomson *et al*., 2013 and references therein). This has prompted a considerable curiosity on: 1) the proportion and distribution of Proterozoic ortho-gneisses with *juvenile* magmatic precursors in the SGT (Kröner *et al*., 2012, 2015; Taylor *et al*., 2015; Vijaya Kumar *et al*., 2016) and 2) tectonic scenarios for the multiple episodes of felsic magmatism responsible for crust formation and recycling during the ~2 billion year geologic record represented in the SGT south of the PCSZ. In this regard, an interesting observation has been that the Trivandrum and Nagercoil blocks include vast stretches of charnockite gneisses whose protoliths represent Paleoproterozoic juvenile magmatism at ~2.1-1.85 Ga (Kröner *et al*., 2012; 2015 and Vijaya Kumar *et al*., 2016).

It was long known that the northern limit of the SGT marks an unbroken prograde metamorphic transition from amphibolite to granulite grade. Further south, the N-S trending structural fabrics of the Dharwar craton have been reworked by the E-W trending mylonitic fabric of the crustal-scale shear zone system, the Palghat-Cauvery Shear System (PCSS), also referred to as the Cauvery Shear Zone (CSZ). In recent years, the tectonic evolution of the PCSS has been resolved broadly into two temporal components, Palaeoproterozoic and Neoproterozoic (spanning the Ediacaran-Cambrian), rather than a single late Neoproterozoic-early Cambrian deformation event inferred in the earlier studies. For instance, around the Moyar-Salem-Attur shear zone at the northern limit of the PCSS, Neoarchean (3.0-2.5 Ga) basement protoliths were shown to be affected by the granulite facies metamorphism during the early Paleoproterozic *ca.* 2.5-2.48 Ga, (Anderson *et al*., 2012; Brandt *et al*., 2014; Mohan *et al*., 2013; Glorie *et al*., 2014; Plavsa *et al*., 2015). In this northern part of the PCSS, many authors interpreted the shear zone systems as cryptic sutures and described several suprasubduction suites including the layered meta-anorthosite and related rock suites of Sittampundi, Bhavani and Gobichettipalayam and other ultramafic-mafic bodies around Attapadi, Kanjamalai and Wynad, considered by some workers as dismembered Paleoproterozoic ophiolite complexes (Yellappa *et al*., 2012; Santosh *et al*., 2012, 2013b; Mohan *et al*., 2013; Collins *et al*., 2014b; Praveen *et al*., 2014; Yang *et al*., 2016). Subsequent retrogression along shear zones associated with metamorphic-fluid channelling to amphibolite and lower grade gneisses has generally been constrained to between ~740 and 500 Ma. At this time frame, the SGT is generally perceived as a key segment of the Gondwana forming orogens such as the Himalayan-scale collisional orogen, the East African Orogen-EAO (Fig. 2) that lay across the continents of Africa, Greater India (parts of Madagascar, Seychelles, India, Sri Lanka) and Antarctica during the Ediacaran-Cambrian, *ca*. 600-480 Ma (Collins and Pisarevsky, 2005; Fritz *et al*., 2013 and Collins *et al*., 2014; Plavsa *et al*., 2015). In this model, the closure of the Mozambique Ocean and the collision of the Indian (Dharwar) and East African/Madagascan cratonic domains is believed to have occurred along the Palghat-Cauvery Shear Zone (PCSZ), in the southern part of the PCSS. Thus, while the deformation in the dextral Moyar-Salem-Attur shear zone of the PCSS is early Paleoproterozoic in age, the PCSZ with dip-slip dextral transpression and north side-up motion has been constrained to *ca.*740-550 Ma. The northern part of the Madurai block may have been deformed in four deformational events, and three of which were contemporaneous to the deformation along the PCSZ and associated with High Pressure -Ultra High Temperature metamorphism and deformation between ~550 and 500 Ma, interpreted as the collisional orogeny of the southern margin of the Azania microcontinent marking the closure of the Mozambique ocean (Santosh *et al*., 2012; Collins *et al*., 2014b; Plavsa *et al*., 2015).

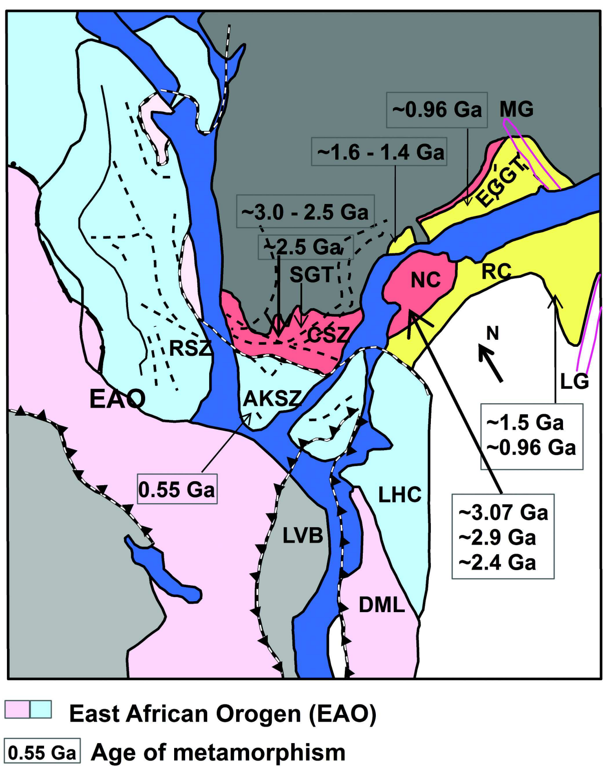

Fig. 2: A schematic of correlation of SGT and EGGT with Grenvillean age and Pan-African mobile belts in E. Gondwana (modified after Collins and Windley, 2002). AKSZ-Achankovil Shear Zone, CSZ-Cauvery Shear Zone, DML-Dronning Maud Land, EGGT-Eastern Ghats Granulite Terrain, LG-Lambert Graben, LHC-Lutzow-Holm Complex, MG-Mahanadi Graben, NC-Napier Complex, RC-Rayner Complex, SGT-Souhern Granulite Terrain, RSZ-Ranotsara Shear Zone, LVB-Lurio-Vijayan Block

Ultra-high temperature (UHT) metamorphism in the EGGT and SGT

Both in the SGT and EGGT, several localities with UHT (T>900°C) metamorphic assemblages are known on a regional scale. During the last quadrennial period, a few detailed studies attempted to link the P-T-t evolution of the UHT rocks to the geodynamic processes. In general, source of heat needed for UHT metamorphic conditions on a regional scale has been a subject of debate (see review by Harley, 2016). One view has been that the UHT may record closure and thickening of continental back-arc basins that are characterized by domains of thinned lithosphere. High mantle heat flow prior to orogenesis and thickening of the hot crust could provide the heat source, while a likely tectonic setting for the back-arc inversion is continental accretion and collision of magmatic arcs. A second view relates the UHT to high radioactive heat production in the crustal column (with higher than average content of heat producing elements; U, Th, and K) involved in a collisional orogeny and crustal thickening. Clark *et al*. (2015) studied UHT conditions in the SGT in relation to the tectonics of amalgamation of the Gondwana. New zircon and monazite ages were presented and linked to the petrological evolution based on phase equilibria in the Madurai Block. These authors concluded that the duration of the high- to ultrahigh- temperature metamorphism lasted for *ca*. 40 Ma with peak conditions achieved *ca*. 60 Ma after the formation of an orogenic plateau related to the collision of the microcontinent Azania with East Africa at *ca*. 610 Ma. Similar studies in the EGGT reaffirm an interval between 1130 Ma and 930 Ma corresponding to a single prograde peak and retrograde metamorphic P-T-t evolution trajectory characterised by nearly isobaric cooling from peak UHT conditions to lower solidi (Korhonen *et al*., 2013). Petrogenesis of the charnockites and enderbites is consistent with their emplacement into hot, subsolidus crust at *ca*. 980 Ma. Final melt crystallization at ~950 Ma suggests maintenance of subsolidus conditions in the crust for about 30 Ma (Korhonen *et al*., 2013; Clark e*t al*., 2013 unpbl. field guide of Intl. Conference on Granulites and Granulites, Hyderabad).

Proterozoic magmatism in Peninsular India

An important development relates to the establishment of $^{207}Pb/^{206}Pb$ baddeleyite Thermal Extraction - Thermal Ionization Mass Spectrometer method for high precision age determination of mafic rocks at CSIR-NGRI (Kumar *et al.*, 2014). Combined with Paleomagnetic and geochemical data, the new baddeleyite age data have contributed to the resolution of emplacement ages of mafic dykes from Dharwar, Bastar, Bundelkhand and Singhbhum cratons. For instance, the identification of giant radial dyke swarm emplaced at ~ 2367 Ma and ~2082 Ma with implications for Paleoproterozoic continental reconstructions and basin evolution (Kumar *et al.*, 2012, 2015; Shankar *et al.*, 2014). Several other researchers have provided new ages, geochemical and paleomagnetic data on the multiple generations of the mafic dyke swarms (*e.g.*, Dash *et al*., 2013), Proterozoic gabbro-anorthosite plutons (*e.g.*, Kaur *et al*., 2013; Dharma Rao *et al*., 2012; Koizumi *et al*., 2014; Raith *et al*., 2014), alkaline complexes, kimberlites and lamproites (*e.g.*, Chalapathi Rao *et al*., 2014; Santosh *et al*., 2014; Karmalkar *et al*., 2014; Hippe *et al*., 2016; He *et al*., 2015) and a host of granitoid plutons and felsic volcanism (*e.g.*, Ashwal *et al*., 2013; Dharma Rao *et al*., 2012, 2013; Meert *et al*., 2013; Ravikant *et al*., 2014) from the different tectonic provinces of peninsular India.

Chronostratigraphy, Provenance and Tectonic Evolution of Purana Basins

Numerous Proterozoic sedimentary basins, well known as *Purana Basins* overlie the $\geq$2.5 Ga Archean crystalline basement in all the cratons of India. These basins comprise thick cyclic successions of psammitic, pelitic and calcareous sedimentary formations, locally associated with mafic and felsic volcanic units. During this quadrennial period there has been a spurt in detrital zircon geochronological studies of major sedimentary formations of the *Purana Basins* of India (e.g., Basu and Bickford, 2014; Turner *et al*., 2014; Collins *et al*., 2015; Joy *et al*., 2015) along with some Re-Os dating of black shale (Tripathy *et al*., 2013), wholerock Pb-Pb dating of carbonates (Gopalan *et al*., 2013 and Rai *et al*., 2015) and Pb-Pb baddeleyite and zircon dating of thermal events (mafic dyke swarms, Kumar, 2015 and granites, Ravikant *et al*., 2014) adjacent to these basins. The data help in constraining the chronology of opening and closing of sedimentation in many Basins and an increased confidence in their chronostratigraphy and correlations thereof. For example, as summarised by Basu and Bickford (2014), the Cuddapah Basin opened shortly before *ca*. 1900 Ma, while Ravikant *et al.* 2014; Kumar *et al.* 2015 opine that this basin formed at about 2000 Ma ago. The Vindhyan Basin opened before *ca*. 1630 Ma, the Khariar Basin likely opened around *ca*.1500 Ma and the Chhattisgarh Basin opened around *ca*. 1400 Ma. The Marwar Basin opened after *ca*. 750 Ma. The Chhattisgarh Basin began to invert at *ca*. 1000 Ma and closed shortly thereafter. The Indravati and the Vindhyan Basins closed around *ca*. 1000 Ma. Collins *et al*. (2015) presented new U-Pb detrital zircon ages along with Hf-isotopic compositions and ^{39}Ar-^{40}Ar white mica ages for different Formations in the Cuddapah-Kurnool Basin and inferred provenances for the different stratigraphic Groups. The Papaghni and lower Chitravati Groups were sourced from the Dharwar Craton, the Nallamalai Group was constrained to be deposited between 1659 ± 22 Ma and ~1590 Ma, sourced from the Krishna Orogen and the Ongole domain to the east of the Cuddapah Basin and temporally correlatable to the Somanpalli Group of the Pranhita-Godavari Valley Basin (Amarasinghe *et al*., 2014 for comparison). The Srisailam Formation also correlates with the Nallamalai Group and is possibly sourced from within the basin. The Kurnool Group was deposited during the Neoproterozoic and sourced from the Dharwar craton. The Gandikota Formation is traditionally considered a part of the Chitravati Group. However, the new detrital zircon ages indicate that this Formation may have been deposited much later, after 1181 ± 29 Ma and possibly correlates with the Kurnool Group. Thus, the new data support linking of depositional events in these probable syn-orogenic foreland basins to their orogenic hinterland and fill-in a ‘missing-link’ in the tectonic development of the peninsular India.

A study of detrital zircon geochronology and zircon Hf-isotopic compositions in the Upper Vindhyan and Marwar Basins (Turner *et al*., 2014) indicated that these basins share some similar source regions, mostly from the Aravalli Supergroup, but may have distinct evolutionary histories. The deposition of the Upper Vindhyan sequence closed toward the end of the Mesoproterozoic (~1000 Ma), whereas deposition in the Marwar Basin was confined to the Ediacaran - Cambrian interval (~570-521 Ma). Turner *et al*. (2014) concluded that the *Purana Basins* of India formed during distinct intervals of Precambrian time, viz. the Paleo-Mesoproterozoic, Mesoproterozoic and

Ediacaran-Cambrian. The formation of these sedimentary basins may be related to tectonics during formation of the supercontinents of Columbia (Lower Vindhyan), Rodinia (Upper Vindhyan) and Gondwana (Marwar). The sedimentary sequences in the Marwar Basin may be part of a large trans-Gondwana series of basins that include the *nearby* Salt Range (Pakistan), Huqf Supergroup (Oman) and Molo Group (Madagascar).

Age of Ore Deposits

Beyond the well known regional framework of mineral deposits and mineral provinces, future mineral exploration would depend critically on the acquisition of further data and the integration on the stratigraphic, structural and tectonic controls with geophysical, geochemical, geochronological and isotopic data. This is because the linkage between deposit type and plate margin processes is being increasingly appreciated, for instance, orogenic gold, volcanic-hosted massive sulphide, Mississippi valley type Pb-Zn deposits etc., which correlate well with supercontinent cycle and continental assembly. Detailed age and isotopic studies on the Indian ore deposits is gaining momentum, some recent examples include: 1) Pb Sequential Leaching (PbSL dating) of U-mineralised Vempalle dolomites, Cuddapah Basin, which suggested that sedimentation and syn-diagenetic U-mineralization occurred in a short interval between ~2000 Ma and 1900 Ma (Rai *et al.*, 2015); 2) U-Th-Pb monazite dating of the Rampura-Agucha and Rajpura-Dariba metamorphosed Zn-Pb deposits, Aravalli Belt, NW India indicating Mesoproterozoic mineralization and variations in Neoproterozoic metamorphism (Hazarika *et al.*, 2013); 3) wholerock Sm-Nd age of 3125 ± 120 Ma for the Nuggihalli chromite deposit (Mukherjee *et al.*, 2012); 4) Paleontological detrital zircon U-Pb age constraint of 980 Ma for the Birmania phosphate deposit marking a new episode of phosphogenesis in NW India and a paleogeographic affinity between India and South China (Hughes *et al.*, 2015).

An Outlook

Although by no means complete or exhaustive enough, this short review brings to fore the sustained interest, national and international, on the evolution of the Precambrian crust of peninsular India. Also the rigor of research in this area is on the rise and this can be ascribed to a greater access to modern laboratory facilities encompassing many more researchers. It is expected that the coming years would witness more significant contributions to the Precambrian geology and geochronology of peninsular India, propelled by the setting up of new laboratories as National facilities as well as the ongoing support to enhance the existing laboratories and research funding in the country by the various Government of India ministries and funding agencies such as; UGC, DST, MoES, CSIR. This is an opportune time for designing and executing major (collaborative) research projects in geochronology and related aspects of Precambrian crustal evolution in India.

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